INTRODUCTION
TO THE
TREATMENT OF DISEASE
BY
GALVANISM

SKENE KEITH

INTRODUCTION

TO THE

TREATMENT OF DISEASE

BY GALVANISM.

INTRODUCTION

TO THE

TREATMENT OF DISEASE BY GALVANISM,

BY

SKENE KEITH,
M.B., F.R.C.S., Ed.
Late Special Assistant Surgeon, Royal Infirmary, Edinburgh.

LONDON:
TRUSLOVE AND SHIRLEY,
7, ST. PAUL'S CHURCHYARD.

PREFACE.

It is not necessary for a physician or surgeon to be an electrician, but he should know something more about electricity than that the sign + stands for the positive and the sign — for the negative pole, before he treats his patient with the continuous current. In the following pages an attempt has been made to give, necessarily briefly and dogmatically, sufficient information for the intelligent use of the continuous or galvanic current in disease. The book is intended for those only, who have no time, and perhaps no inclination, to study larger works on the subject.

SKENE KEITH.

42, CHARLES STREET,
BERKELEY SQUARE, W.

CHAPTER I.

DEFINITION.

In electrical science the words Positive and Negative continually recur. Benjamin Franklin first used these words to denote different sets of phenomena. He held a theory, and the words conveyed to him a very definite meaning. The words Positive and Negative will be used in this book with as little meaning as possible attached to them, and merely as implying that there seem to be two forces, which act in different directions. What has hitherto been called Positive will be positive still, and Negative will be negative still, because this has been established conventionally; but there will be no claim advanced for the one to be considered the more positive.

When the old philosophers rubbed a piece of glass with silk, they said that the glass manifested vitreous electricity. Franklin called it Positive electricity. When they rubbed resinous things with flannel, or better, with the fur of a cat, they said that the resinous thing manifested resinous electricity. Franklin called this Negative electricity. The sets of phenomena are different, and by convention we adopt the words Positive to denote the first, and Negative to denote the second. It, then, merely becomes necessary to use the words consistently.

Long ago it was known that similar electricities repel, and that dissimilar attract. If two pieces of glass tube be rubbed with a dry piece of silk, and suspended each by a dry silken thread, they will repel

each other. Here we have two positively electrified bodies, or, as the ancients would have said, bodies charged with vitreous electricities, repelling each other. Now, if a piece of some resinous substance, for instance, an ebonite penholder, be rubbed with fur, or say flannel, it will be attracted to, and will attract, the positively electrified glass. The penholder has resinous, or Negative electricity, and attracts the glass, which has been charged with unlike electricity.

Electrified bodies attract unelectrified bodies. A piece of electrified glass—that is, glass which has been smartly rubbed with dry fur—will attract towards it light bodies, which have undergone no electrification.

A pith ball, suspended by a silk or any other non-conductive fibre, will be attracted by an electrified glass rod. The explanation usually given, is that in the unelectrified pith ball, a separation of electricities occur—the unlike electricity is attracted towards the electricity of the glass rod, and the like is repelled.

It might be expected that as the pith ball is both repelled and attracted, there would be no motion of any kind owing to the equal forces acting in opposite directions. It is easy to see, however, if a diagrammatic representation be made, that the electricity on the pith ball which makes for attraction to the electrified glass, is nearer than the electricity on the pith ball that makes for repulsion.

If it be admitted then—the law has been laid down after many experiments have been made—that the attraction varies with the proximity of the bodies, then it will be seen, that though attraction and

repulsion co-exist; yet, because of the fact that the attracting electricities are nearer, the attraction is greater than the repulsion.

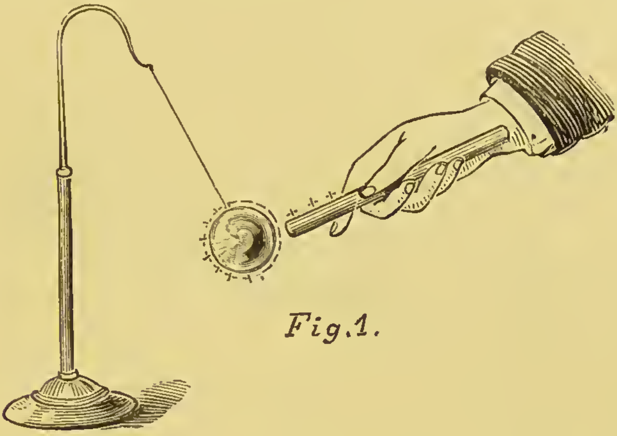

Fig. 1.

With the electrical pendulum, all the kinds of attraction and repulsion may be demonstrated. The pith ball may be endowed with any of the kinds of electricities, or it may, as in Fig. 2, have an equal quantity of each. When it is as in Fig. 2, it is said to be "unelectrified" or "neutral."

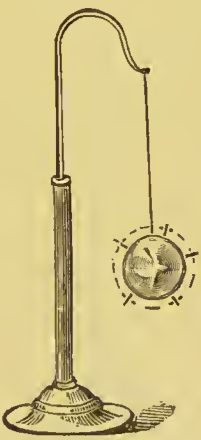

Fig. 2.

Fig. 1, then, shows the *attraction* which such an unelectrified body has for a positively electrified body, as, for example, a piece of glass which has been rubbed with silk.

Fig. 3 shows the *attraction* which such an unelectrified body has for a negatively electrified body, such as an ebonite penholder, which has been rubbed with flannel or catskin.

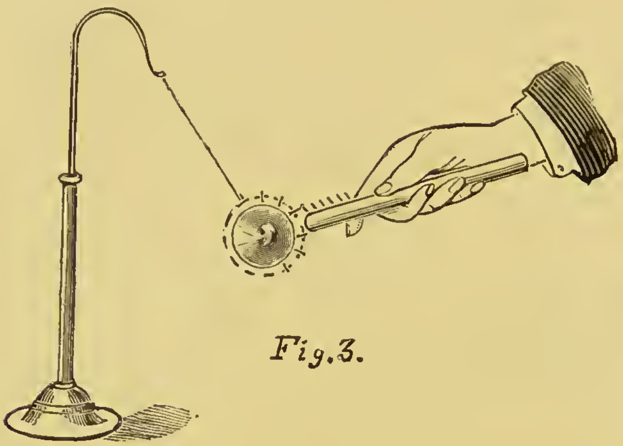

Fig. 3.

The pith ball may itself be endowed with electricity of either kind. If it be actually touched by an electrified body it will become endowed with that kind of electricity. If it be touched with excited glass, it will become positively charged.

Fig. 4. represents a pith ball positively charged.

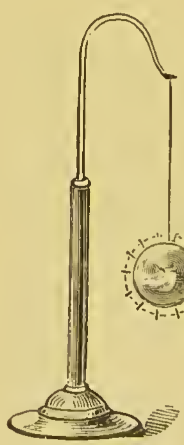

Fig. 4.

If it be approached by excited glass, repulsion will ensue, as diagrammatically shown in Fig. 5.

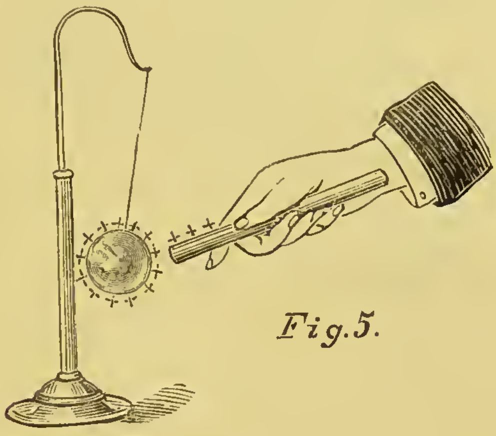

Fig. 5.

If it be approached by excited vulcanite (a negatively charged body), attraction will ensue, as shown in Fig. 6.

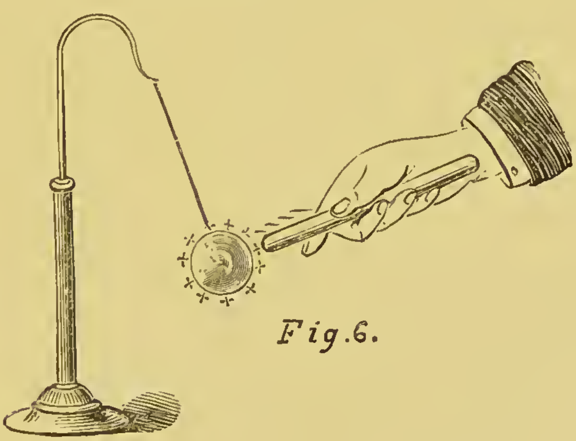

Fig. 6.

The ball might be endowed with negative electricity, by touching it with the excited vulcanite instead of the excited glass; then the diagrams 7 and 8 would represent the states of things; when such an electrified body is approached: by a similarly electrified body: or by a dissimilarly electrified body.

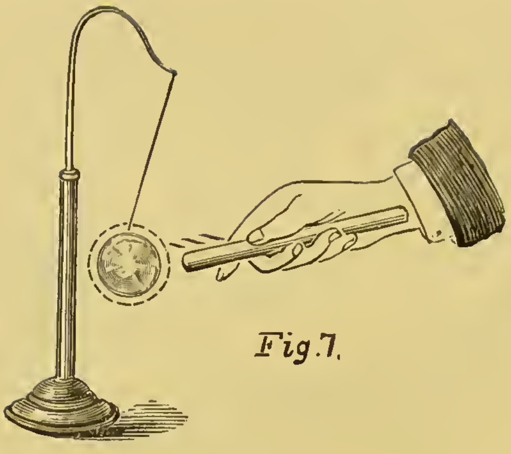

Fig. 7.

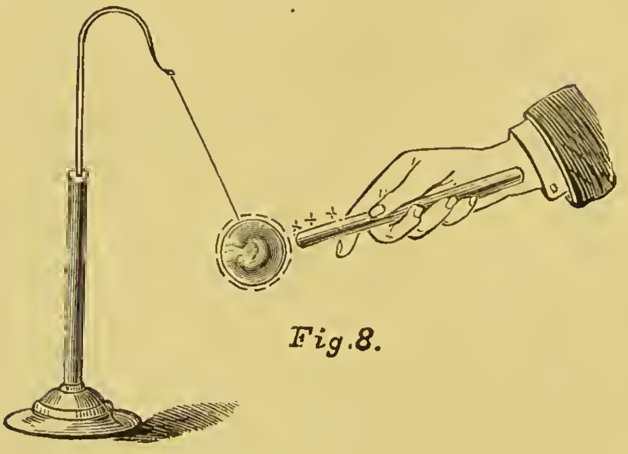

Fig. 8.

CHAPTER II.

CONDUCTORS AND INSULATORS.

In the simple experiments with glass and ebonite described in the introduction, the glass and the ebonite penholder were directed to be suspended by dry silk threads. If, for the silk thread, there were substituted a metal wire, or even a moistened thread, the electrical manifestations would be feeble, or perhaps undetectable. If, instead of experimenting

with a piece of glass, a piece of metal be rubbed, the said piece of metal being held in the unprotected hand, no electricity will be available, whatever the amount of friction employed. From this, it was argued that certain materials, which manifested electricity when held in the hand and rubbed, were "electrics;" and certain others, which did not manifest electricity when similarly manipulated, were "non-electrics." The nomenclature was wrong, for all materials may be electrified; and, in the case described, namely, that of the rubbing of a metal, some result will be obtained, if the portion of the metal held by the hand be surrounded with some so-called "non-electric," or, as it had better be called, some insulator or non-conductor. Indeed, for the words "electrics" and "non-electrics" used in the older text books, we may uniformly substitute the words conductors and non-conductors; and, as it will be hereafter seen that even these differ only in degree and not in kind, we may speak of good and bad conductors, instead of using the words conductor and non-conductor.

All substances of different kinds may be electrified by being rubbed against one another. From what has been seen, it will be plain, that, to obtain evidence of this electrification, the substance to be examined must be well insulated, so as to ensure that its electricity will not have flown away. before it has been possible to test its presence. It may be asked. Where does it flow? It flows to the earth, which, so far as electricity is concerned, may by analogy be likened to a morass, capable of yielding any amount of water, and of absorbing any amount. It is, as a matter of fact, often called the common reservoir. The current, when electricity passes

between a positively electrified body and a negatively electrified body, as, for instance, along a conductor like a metal wire, is, by convention, said to be in that direction, which leads from the positively to the negatively charged body.

CHAPTER III.

DISCOVERIES OF GALVANI AND VOLTA.

Towards the end of last century, some experiments made by Galvani induced many men, and especially Volta, of Pavia, to study hitherto unnoticed electrical phenomena. Galvani, so the story goes, had prepared some frogs in order to make a *potâge* for his wife. The hind legs only of frogs are used in cookery, and some of these, transfixed by copper hooks, had been hung thereby to the iron balcony, on which the *savant* stood. The hooks, it must be supposed, were inserted near to the large nerves passing to the leg. It is believed that Galvani had previously made some experiments with electrical machines and frogs, and he now noticed that, when by chance, the suspended legs touched the iron railing, twitchings of the limbs took place. Galvani formed a theory, and wrote about it; but he does not appear to have appreciated, as did Volta, that the great discovery lay in this, that contact of two metals (in this instance copper and iron), resulted in the separation of electricities. Volta, who, though not the first discoverer, was certainly the first good commentator on the subject, proceeded to make experiments, and, in the last year of last

century, constructed what we now know as the Voltaic pile.

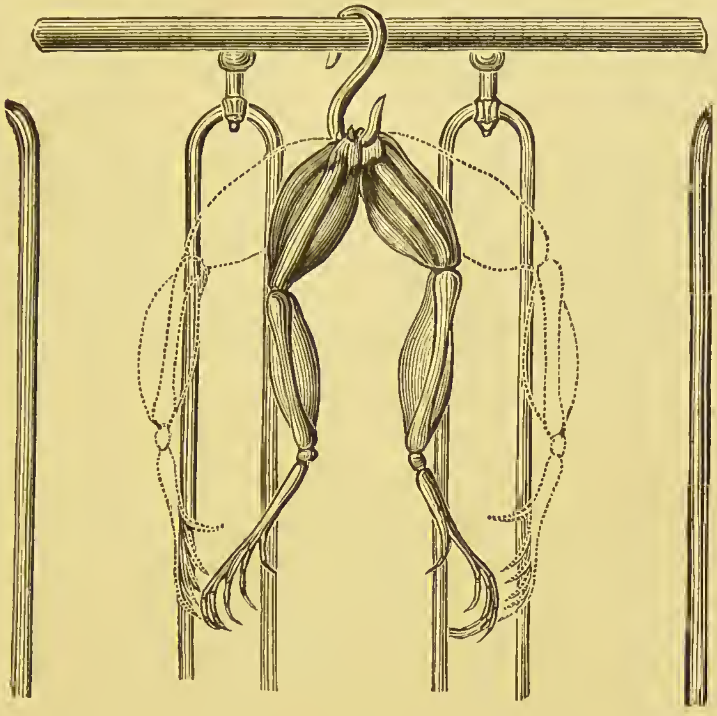

Fig. 9.

We must consider for an instant what it was that Galvani had really seen, and what explanation Volta gave of what had occurred. The limbs of the frogs were transfixed by copper hooks, and these hooks were in contact with the iron railing of the balcony. In this condition nothing happened, but when the wind blew the frog's leg against the iron railing, Galvani noticed that a twitching of the leg occurred. In Fig. 9, we have the condition, and in outline we have the copper and iron already connected by one juncture, again mediately connected by means of the leg of the frog (Fig. 9). Indeed, there had been constructed for Galvani a cell, of which the copper hook was one, and the iron railing the other element,

the moisture in the frog's leg was the electrolyte or material susceptible of chemical separation, and the nerve and muscle an extremely sensitive electroscope, or instrument for detecting the presence of electricity.

CHAPTER IV.

THEORY OF THE VOLTAIC CELL.

It is unnecessary to relate the controversy which arose between Galvani and Volta. Each advanced theories, and each upheld his own theory with vigour and ingenuity. Volta's theory, with some modifications, is that which offers a reasonable explanation of the phenomena of what are sometimes called Galvanic, sometimes Voltaic, cells; and it was Volta, who, departing from the elementary form, accidentally hit upon by Galvani, first constructed a Voltaic cell, and from a collection of cells, a Voltaic battery (Figs. 10 and 11).

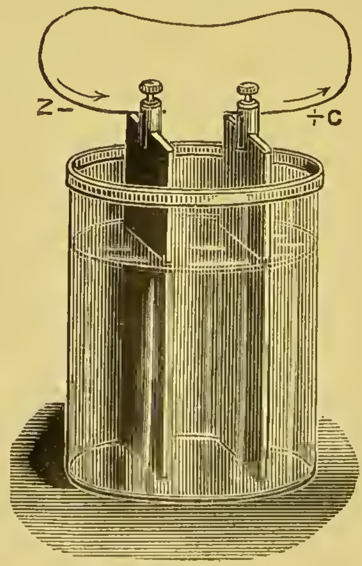

Fig. 10.

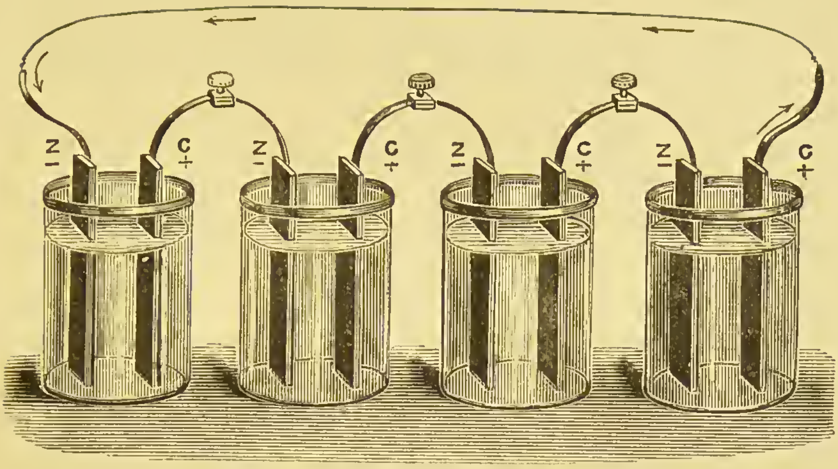

Fig. 11.

It is not, in some respects, very profitable to speculate about those principles of action or advance theories, which the future may well show to be untenable. It is, however, necessary, in order the better to systematise such facts as we are possessed of, to formulate or accept some reasonable hypothesis. It is very necessary to remember, that such must not in any case be accepted as a statement of ascertained facts, even when, for convenience in writing, positive assertions are made.

If two metals—and at present the case of metals only will be considered—be made to touch, there is brought about a separation of their electricities, much in the same way that there is, when, in the experiments described in the opening chapter, glass is rubbed with silk, or ebonite with flannel.

A list of metals might be made, in such order, that the higher in the list would always be electro-positive; that is, electricity would flow, in favourable circumstances, to any other lower in the list. If two metals

be taken, such as copper and zinc, and brought together, it would certainly be found, on using suitable apparatus for testing, that the zinc is electro-positive to the copper or to state the case differently, the copper is electro-negative to the zinc. The electrical difference is, however, not great, but with such difference as there is, would it be possible, by making such an arrangement as that figured, to obtain a current? It would not be possible, for, though there

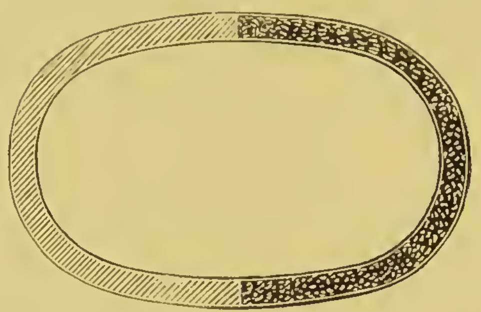

Fig. 12.

would, at the upper junction of the two metals, be a separation of electricities, positive passing to the zinc and negative to the copper, there would be a similar separation at the lower junction, and the zinc would therefore remain charged with positive, and the copper with negative, electricity; there would be nothing of the nature of a circulation. A current could be obtained, however, if this separation at the lower junction could be done away with, or its effects neutralized; while, of course, retaining the separation at the upper junction.

Volta's arrangement allows us to secure this, and it does so in the following way. The lower junction is done away with, and the two now disunited ends are placed in water, which is made a better conductor by the addition of some salt or acid. The water is

called the electrolyte, and it is profitable in this connection to remember that the frog's legs in Galvani's experiment contained water, which served, in his accidentally constructed cell, the same function as the liquid in the Voltaic arrangement, now being described.

A molecule of water is composed of atoms of hydrogen and of oxygen, and the behaviour of these atoms, in the presence of the positively electrified zinc and negatively electrified copper, provides the means of neutralizing the electricities at the lower ends of the zinc and copper. If, as fast as the electricities get to the lower ends of the zinc and copper, they be neutralized; and, if it be considered a fact that the electrical separation goes on at the upper junction of the metals, then there will be a constant passage of positive electricity down the zinc and of negative electricity down the copper; because the source of the electricities is at the upper junction of the zinc and copper, and as fast as the electricities pass down they become neutralized in the manner to be described.

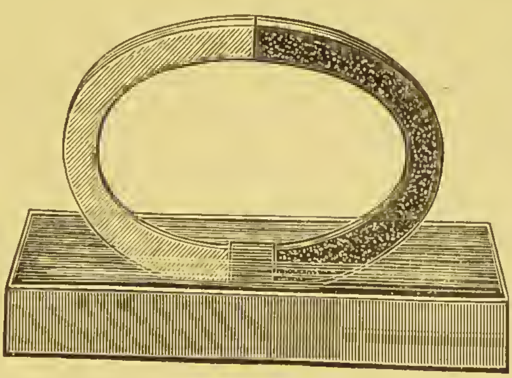

Fig. 13.

It is well known that water is made up of molecules which contain combining proportions of hydrogen and oxygen, represented by the chemical symbol H_2O It will have to be assumed, meanwhile, that the molecule of water is capable of splitting up into

hydrogen and oxygen. That this is really so will be afterwards seen, when the electrolysis of water comes under consideration.

There is some reason for supposing that hydrogen is a gaseous metal, and, assuming that this is so, it would stand higher than copper in the aforementioned list of metals, in which those higher in the list are positive to those lower in the list. It will be then positive, and copper will be negative, and as bodies charged with unlike electricities attract, we shall expect that the hydrogen will pass to the copper. This, beyond all doubt, it does. In passing to the copper, it gives off its positive electricity to the copper, and thus neutralizes the negative electricity at the lower end of that metal. When it has parted with its negative electricity it escapes, or, at least, ought to escape as gas.

In a similar way, the oxygen is electro-negative to the electro-positive zinc and passes towards it, neutralizing, on contact, the positive electricity of the zinc. The nascent oxygen unites chemically with the zinc, and oxide of zinc is the product. The oxidation or combustion of the zinc or other oxidizable metal is essential to the action of all batteries of the Volta type.

If, then, it has been demonstrated that by the behaviour of the hydrogen and oxygen the electricities, which flow down the copper and zinc are neutralized, it will be clear that so long as the separation goes on at the upper junction, currents of positive electricity will flow down the zinc and of negative down the copper. But a current of positive electricity flowing downwards is the same as a current of negative electricity flowing upwards; and, one of negative electricity downwards is the same as one of positive upwards. It is, therefore, quite correct to say that the

positive current flows up from the copper in the water or electrolyte, and that the negative current flows up the zinc. This is a more convenient way of stating the fact, as in practice the vessel containing the metals is considered as being the starting point of the currents.

In the diagrammatic representation of the Voltaic arrangement (Fig. 13) the copper and zinc are actually in contact, but this is not necessary. Instead of that the two metals may be connected by a conductor of electricity, as is shown in Fig. 10, which is a drawing of a single cell of a Voltaic battery.

The statement, which has been made, that the action is supposed to commence in the electrolyte, and that a current of positive electricity flowing down the zinc is the same as a current of negative flowing up that metal; and a current of negative electricity flowing down the copper is the same as a current of positive flowing up, explains why the copper, which is the negative element, is called the positive pole and the zinc the negative.

CHAPTER V.

POLARIZATION.

The cell described in the last chapter would not be a good one, if the property of giving a steady current for a considerable length of time be considered as goodness in a cell. When the behaviour of the hydrogen was spoken of, it was mentioned that it ought to escape as gas, after having given up its positive electricity to the negative copper. This is what it certainly ought to do; but, unfortunately, it does not do so. On the contrary, a large portion of it collects, sticking as a gaseous covering to the copper plate. Hydrogen is a bad conductor, and by its presence prevents the molecules of hydrogen behind, from

parting with their electricity to the copper. Indeed, if it has collected in sufficient quantity, it brings the whole cycle of operations to an end, and this, not only on account of the resistance which it offers to the passage of electricity, but by setting up on its own account as a plate in the cell, and tending to cause a current in the opposite direction to that of the original current. Hydrogen, as has been seen, is useful, and, in fact, essential in such a cell as has been described. It serves as a carrier of positive electricity, but its existence after that function has been performed becomes a source, not only of embarassment, but even of actual stoppage of the electrical current. The Voltaic current might say of hydrogen, "*Tecum non possum vivere, nec sine te.*"

Hydrogen, then, having done its duty, must be got rid of, as in certain insect communities the males are got rid of as soon as the object for which they were made has been accomplished.

The troubles due to the presence of hydrogen are known to electricians by the name of polarization, and the remedies employed for getting rid of them are called depolarizers.

CHAPTER VI.

OF CELLS.

In some cells attention has been directed to affording easy ways of escape for the hydrogen bubbles of gas. The negative plate has been roughened or made like a file, as bubbles of gas do not stick to such plates, so easily as they do to smooth ones. Stronger remedies than this are required, and in all cells of practical value to be considered, it will be found, that there are means employed for getting rid of the hydrogen as soon as it has done its duty, or for getting it to give up its carrier functions to another

messenger less mischievous; the hydrogen itself becoming united with the now mateless substance to whose previous partner has been deputed the carrying function. In union with this substance the hydrogen may be inert, or may even serve some useful end, while its new substitute in the carrying business may have none of its predecessors bad qualities as a messenger.

The type of cell which uses the gentler method of inducing the hydrogen to go away quickly is represented by the Smee cell (Fig. 14). In it, a plate of platinised silver, roughened so as to present no foothold for the gas, does duty for the negative plate, the positive plate being zinc and the electrolyte water and sulphuric acid.

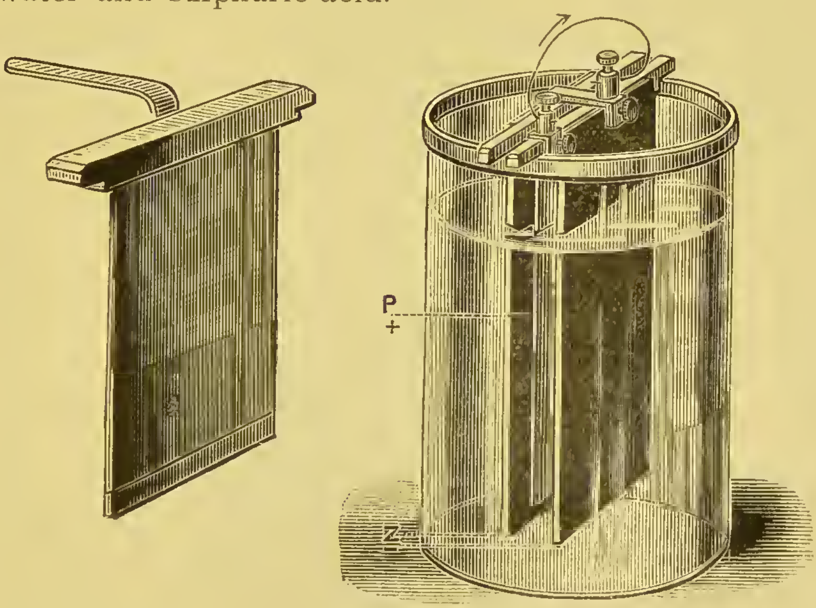

Fig. 14.

Shaking the negative plate is sometimes had recourse to for the purpose of assisting the bubbles to get clear of its surface; and sometimes air is blown into the cells for a like reason.

A cell, which depolarizes by destroying the hydrogen by oxidation after it has done its work, is that known as the Bunsen cell (Fig. 15). In this cell we

find that, as in nearly all cells, the positive element is zinc; for its negative element, it has a plate of hard carbon, of the kind known as retort carbon, called so because it is obtained from the gas retorts. Instead of a single vessel for the zinc and carbon plates, there are, in the case of the Bunsen cell, two vessels, an outer and an inner one. The outer vessel is of some impervious material, the inner is of porous earthenware.

Between the outer and inner vessel is placed the zinc or positive plate, immersed in a dilute solution of sulphuric acid in water. In the inner and porous cell is placed the carbon plate or cylinder, immersed in nitric acid. Nitric acid is, as is well known, a powerful oxidizer, and its function in destroying the hydrogen molecules is performed very satisfactorily. The Bunsen cell has the disadvantages of requiring two fluids; these gradually mix through the porous septum; and above all other faults is this, that it gives off disagreeable and even poisonous fumes.

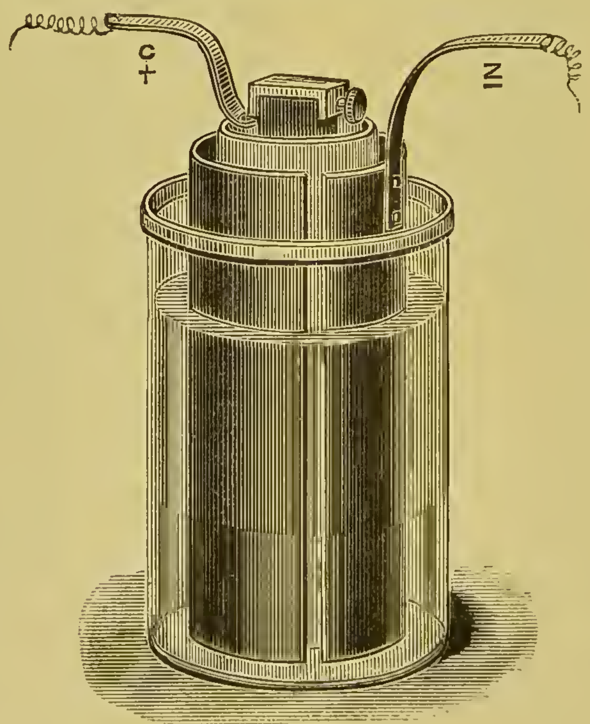

Fig 15.

The Grove cell is the same as the Bunsen, with this difference, that platinum is used as the negative element instead of carbon.

The Bichromate cell (Fig, 16) employs one receptacle, and its elements, as in the previous case, are zinc and carbon. The electrolyte is water and sulphuric acid, and in this is dissolved some bichromate of potash, or better, bichromate of soda, both of which are oxidizers.

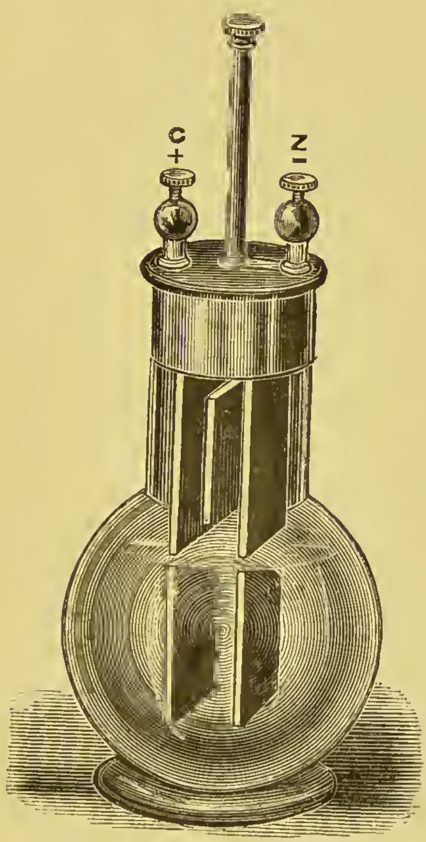

Fig 16.

The Bichromate cell, especially in the form known as the bottle cell, is a very convenient and satisfactory one for many purposes, its special feature being the means provided for withdrawing the zinc from the solution, when the cell is not required to be in action. Sometimes the bichromate cell is made up with an

inner and porous vessel, which contains chromic acid surrounding the carbon, but in such an arrangement there is very little advantage over the Bunsen cell. The Bichromate bottle cell, on the other hand, with a single fluid, is elegant and convenient, while there is no particular advantage gained, if its simplicity be done away with.

The cell, which adopts the plan of substituting for the mischievous hydrogen a better form of carrier, is that known as the Daniell cell. (Fig. 17.)

This cell, in one of its forms, resembles the Bunsen in respect that it has an outer and an inner vessel, the latter being porous. The positive element is zinc, and the fluid surrounding it, is dilute sulphuric acid. In the inner and porous pot is placed the copper or negative element, surrounded by a saturated solution of sulphate of copper. In setting up a Daniell cell, however, it is not necessary or even customary to fill the outer cell with sulphuric acid, for water alone will serve, provided that the two plates of the battery be for some time joined by a conductor. Sulphuric acid is manufactured by the action of the cell, and this attacks the zinc, forming with it sulphate of zinc. The hydrogen, which is set free when the zinc replaces it ($H_2O,SO_3 + Zn = Zn \frac{O}{wc} SO_3 + H_2$), does not remain as free hydrogen, but, on passing through the porous system towards the negative copper plate changes places with the atom of copper in a molecule of sulphate of copper, and transfers to the copper molecule the function of carrying positive electricity ($2H + CuO,SO_3 = Cu + H_2O,SO_3$). A copper particle or messenger thus goes to the copper plate, and it, of course, does not act in the detrimental way in which the hydrogen does.

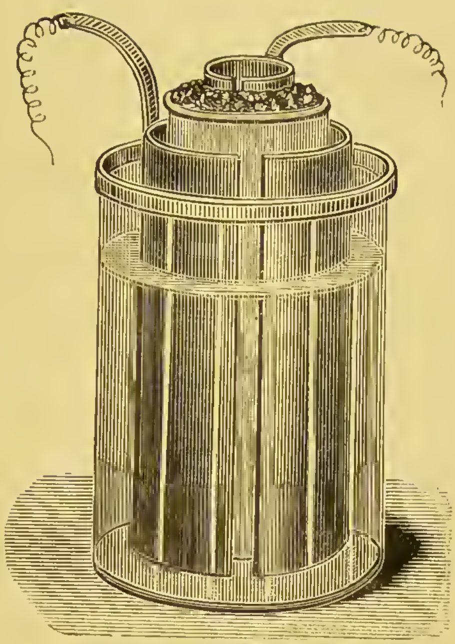

Fig. 17.

In some forms of Daniell cells the porous pot is dispensed with, and a mass of either sawdust or sand or paper pulp is placed at the bottom of a vessel, and above the copper plate. The mass is then saturated with a solution of sulphate of copper. Above this, is the liquid composed of dilute sulphuric acid and sulphate of zinc. It has been found, however, that the two liquids can be kept separate without these precautions, for the different specific gravities of sulphate of copper and sulphate of zinc may be depended on to maintain this separation. Accordingly, what is called the gravity cell is now frequently used. This consists simply in an arrangement such as that shown in Fig. 18.

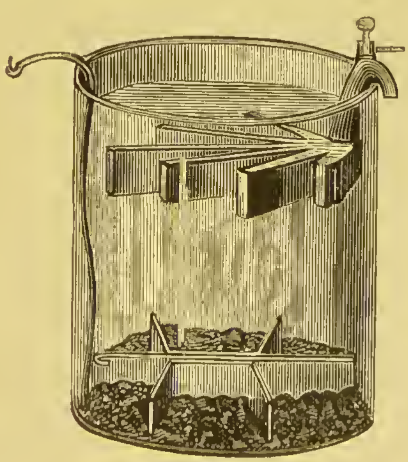

Fig. 18.

To get the cell into working order, it is merely necessary to connect, for a few hours, the terminals of the zinc and copper. If it should be wanted to work at once, a little sulphuric acid must be dropped gently into the water. This is best done by means of a pipette, whose end is inserted under the surface of the liquid. Every now and again it is necessary to draw off with a syringe, or in some other way, which will disturb the liquid as little as possible, some of the sulphate of zinc solution from the top of the fluid, and replace with water. If the zinc become coated with a black deposit, called by the post-office battery men "black mud," this should from time to time be removed. If the Daniell cell be occasionally looked after, it will continue to work satisfactorily for a long time, and it has this great merit, that the current, which it yields, is for a long time nearly constant in character. The Daniell cell is, therefore, extremely useful for testing purposes, and where a steady current is necessary.

CHAPTER VII.

OF CELLS.

Amongst the innumerable number of cells, which have come forward in late years, there is one which is pre-eminently useful to all, who wish for a cell, which shall give the minimum amount of trouble. The Leclanché cell gives next to no trouble, and it may, and often does, last in good condition for many months without any attention whatsoever. This cell is made in several varieties, and a wise choice of the form, which will best suit the special purpose, will often prevent disappointment, and the occurrence of doubts as to whether the cell has, after all, the excellencies which its friends claim for it. There are at least two forms which are well known to dealers in

electrical apparatus. There is the porous pot form, which, as its name implies, contains an inner porous pot. In this, is placed the carbon element, surrounded by small fragments of crushed carbon, and of binoxide of manganese. The binoxide, or black oxide of manganese, is in the Leclanché cell the depolarizer or oxidizer. The exciting solution is water, in which is dissolved muriate of ammonia, otherwise chloride of ammonium or sal ammoniac. The positive element is zinc. Chloride of zinc is the result of the action of the fluid upon the zinc when the current is closed, and the black oxide gives off oxygen, which combines with the liberated hydrogen.

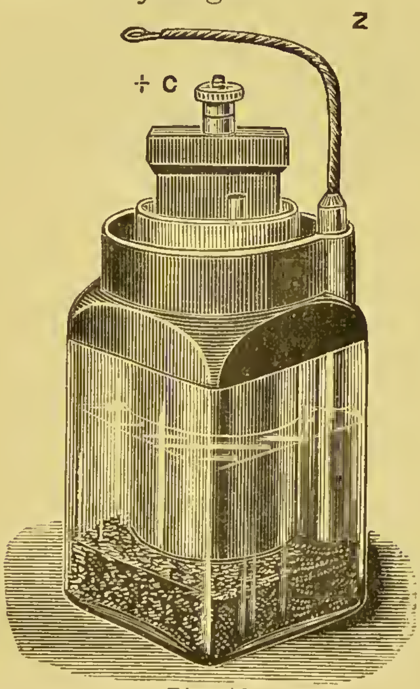

Fig. 19.

In another form of Leclanché cell, known as the "agglomerate block," the binoxide is made into a paste with carbon, and the mass is, in one way or another, consolidated into cakes, which are fastened to the carbon plate serving as the negative element. In this way the necessity for a porous pot is done away with, and certain advantages are secured,

which will be understood when the question of internal resistance is studied.

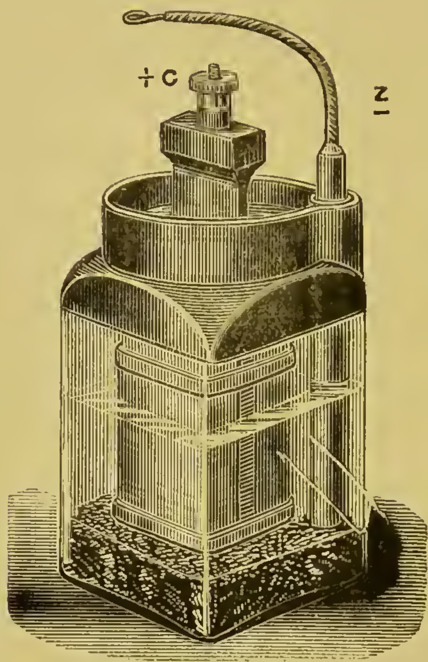

Fig. 20.

There is another form of Leclanché cell, which, for its convenience to all who require a portable cell, and because of a curious property which it possesses in common with secondary cells, deserves mention here. The cell is the invention of Dr. Gassner. It is contained in a hollow zinc cylinder, which serves as the positive element. An inner hollow cylinder of carbon is the negative element, and the excitant is an ammoniacal salt intimately mixed with plaster of Paris, whose water of crystallization is said to be available for the production of the necessary hydrogen. An oxide of zinc, mixed with the plaster of Paris and ammoniacal salt, provides the depolarizing oxygen. The cell, when exhausted, can be refreshed by charging it from another source of electricity, in the way, that secondary cells of the Planté and Faure type are charged.

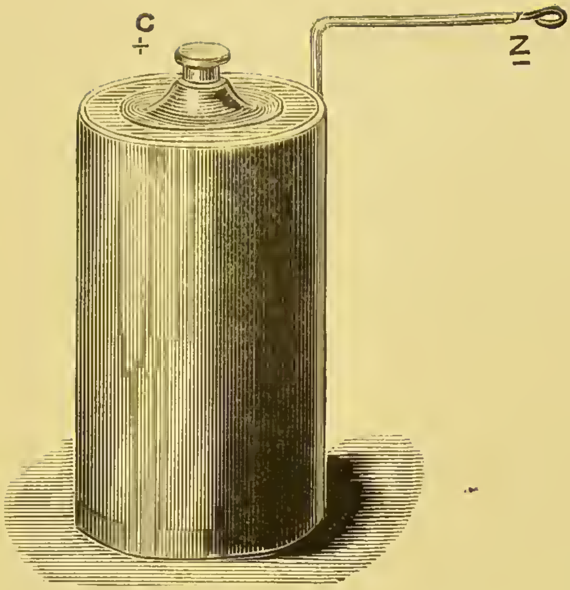

Fig. 21.

A cell, very popular in France, and owing to its introduction into England, under a new name and in many ways improved, now a good deal heard of, is the sulphate of mercury cell, due to Marie Davey. As in the Bunsen, two vessels are employed in this cell. In the outer, which contains the zinc, there is placed water or brine. In the inner and porous vessel is a paste of sulphate of mercury, and a solution of the same. When in action the zinc decomposes the water, and hydrogen is liberated. The hydrogen displaces the mercury in the sulphate of mercury, and sulphuric acid and metallic mercury result. The mercury remains as mercury, and the sulphuric acid attacks the zinc. In the newer forms of this cell, no porous pot is required.

In all the cells which have been described, with the exception of the first, it will have been noticed that provision has been made for avoiding the polarization, due to the presence of hydrogen. Some arrangements effect this better than others, and so far as the virtues and vices of cells have yet been considered, the enduring efficiency of the depolarizers, together with

absence of objectionable fumes, facility of handling, etc., would seem to determine the best cell. There are, however, other points to be considered, and to understand them it will be necessary, that some study should be made of the questions of electro-motive force and internal resistance, as they affect the various cells already described.

CHAPTER VIII.

OF POTENTIAL.

When speaking of the theory of the Voltaic cell, it was mentioned that any two metals undergo, if brought in contact, separations of their electricities at the point of juncture. It has been seen, that these electricities are, in a Voltaic cell, neutralised by the molecules of the liquid in which they are immersed. In these facts lie the possibility of obtaining a current of electricity from a Voltaic arrangement. It has also been pointed out that a list of metals can be drawn up, in which that metal highest in the scale will be highly electro-positive to the metal lowest in the scale, while varying degrees of difference exist between all metals, according to the distance, by which they are separated from each other in the list.

Elements, arranged in such order that each higher would be electro-positive to each lower in the list, would, on a study, show an arrangement in order of their affinity for oxygen. Thus:

Zinc,
Lead,
Iron,
Copper,
Silver,
Gold,
Platinum,
Graphite,

is a list of elements arranged in electro-motive series and also in oxydisable series. Zinc would be selected as a highly oxydisable body, and platinum or gold or graphite, as bodies having but small affinity for oxygen; and, in constructing a cell, the most readily oxydisable element would, *cæteris paribus*, be selected for the positive plate, and the least oxydisable element for the negative plate.

This diffierence is expressed as being a difference of potential. What is meant by difference of potential between two metals, will be understood if the idea, which the word conveys in other connections, be thought of. It is said of a lake that it has potential, due to its height above the sea level. This is expressed in terms of vertical measure, and the lake is said to have a potential or "head" of, for instance, 100 feet, and one understands exactly what is meant, viz., that there is a potential energy, due to the vertical height above the level of the sea, which is expressed in terms of vertical height—the unit in in England being the foot. In order to form a conception of "head," or "potential," it is not necessary to ask through what conduit the water will pass to the lower level. This fact is, of course, of great importance, as affecting the amount of useful work the water issuing from the lake may be made to do; that being dependent, of course, upon other things beside potential, though this will always remain an important factor to be reckoned with.

So, with those things that go to make an electrical current, difference of potential has to be considered as one factor. Now, all metals are at different potentials to one another in air. Potential might be defined as that which confers the power of overcoming resistance. If it be said of a cell that it has a high potential, what

is meant is, that there is a greater power in that cell than there is in a lower potentialed cell of sending the current through resistance. While this is so, it does not follow that a cell of higher potential will, when its plates are connected by a good conductor, necessarily send a larger current than a lower potentialed cell, whose terminals are similarly connected. When resistance is spoken of, the sum of the resistance in the circuit has to be taken into consideration, and this must always include the resistance of the liquid between the plates in the cell. This resistance varies very much according to the size of the plates, to the distance they are apart, and also, according to the kinds of liquids, which are used. If the internal resistance, that is, the resistance in the cell itself, be the same in a high and in a low potentialed cell, and the wire joining the poles be also of the same resistance, then undoubtedly, the higher will yield more current than the lower potentialed cell.

It has been stated, that the metals can be arranged in a list showing their relation to one another, as regards the question of whether one is electro-positive or electro-negative to another. As metals always bear this relationship to one another, it will be evident that the difference of potential between the elements of any one cell will be always the same, though the effective potential may be lessened by the existence of contra electro-motive force, due to polarization. The electro-motive force is also always the same in any one cell. In a Daniell cell, for example, it is slightly more than one volt, in a Bunsen or Grove cell nearly two, in a Leclanché about one and a half, and so on. The electro-motive force remains always the same, no matter what is the size of the cell, or in what relation are the elements.

But with resistance in the battery itself, the case is entirely different. Taking our old example of the lake 100 feet above the sea level, it will be at once seen, that more work will be done by the water flowing down through a pipe, than would be possible, if the same pipe were filled with stones or any other material. Less work would also be accomplished if the water were flowing through a pipe which was half the diameter of another. So, too, is it with a Voltaic cell. Less current will flow, if there be increased resistance in the cell, and there will be the same result if the elements be reduced in size; because while the head or potential remains the same, fewer paths will have been provided for the current to pass.

To Ohm belongs the credit of making the rule for the determination of the strength of current in a circuit. This rule may be expressed thus, the current is equal to the electro-motive force divided by the sum of the resistances.

To use this rule it will be necessary to have units of force and units of resistance.

CHAPTER IX.

OF CURRENTS.

The unit of electro-motive force is called a volt, the unit of resistance an ohm, and the unit of current an ampère. These units are scientifically derived from units of length, mass, and time. The letters E or EMF are used to denote electro-motive force, R to denote resistance, and C to denote current. Ohm's law is expressed thus: C, the current, equals E, the electro-motive force, divided by R, the resistance, or symbolically $C = \frac{E}{R}$. It is found convenient to let R stand for external, and R^1 for internal resistance. Assuming that a cell has an electro-motive force, or

E, of one volt, and that the internal resistance is one ohm, we have, when the elements of the cell are joined by a wire, whose R is negligeable, $\frac{E=1}{R^1=1}$. This gives 1 as answer in terms of ampères. It may, therefore, be said that the unit of current is that supplied by a cell, whose E is 1, and whose R^1 is 1, R being negligeable.

If Ohm's law may be written $C=\frac{E}{R}$

it may also be written $E=CR$

and $R=\frac{E}{C}$

Unit current may be defined as the current with unit E and unit R, unit electro-motive force as E with unit C and unit R, unit resistance as R with unit E and unit C.

When the values of two factors are known, it is possible to ascertain that of the third by calculation. Thus, supposing that the electro-motive force of a cell and its internal resistance are known to be respectively 2 volts and 5 ohms, to find the current which the cell will yield on short circuit, that is when the external resistance is negligeable, 2 (the EMF expressed in volts) is divided by 5 (the R^1 expressed in ohms), and the result is $\frac{2}{5}$ = 0·4 ampères, or 400 thousandths of an ampère, written 400 milliampères for convenience. But, as a rule, in using currents, external as well as internal resistance will have to be taken into account, and it will be found that, if the external resistance be large, the current will be greatly diminished. Taking a case where the external resistance is 195 ohms, using the same cell as before, it is now found—

$$\frac{2}{5\left(\substack{\text{internal}\\\text{resistance}}\right)+195\left(\substack{\text{external}\\\text{resistance}}\right)} = 200\,)\;2{\cdot}00\;(\,0{\cdot}010 \text{ ampères,}$$

ten milliampères only, as against four hundred milliampères in the previous case, when there was no external resistance.

It will be seen from the foregoing statements, that the calculation necessary to determine what number of cells will be required to send a current of so many ampères or milliampères demands knowledge of several things. It is necessary to know the voltage or potential of the cell. It is necessary to know the internal resistance of the cell, and also the resistance of the external circuit.

A battery, made up of cells of a certain internal resistance, will yield a very different current to that produced by another battery, the same as to voltage or potential, but differing as to internal resistance. To appreciate this, the case of two batteries may be taken, each made up of ten cells, each cell having a potential of one volt. Let the internal resistance of each cell of the first battery be one ohm, and that of each of the cells of the second battery be ten ohms, the external resistance of both circuits being supposed to be negligeable. Setting the two calculations side by side, there is in the first case $\frac{E\ 10}{R^1\ 10} = 1{\cdot}000$ or one ampère. In the second case $\frac{E\ 10}{R^1\ 100} = 0{\cdot}100$ or 100 milliampères. In the first case there will be a ten times greater current than in the second.

In the foregoing calculation it was assumed that the external resistance was negligeable. Into the external circuit of each of the two batteries, place a large external resistance, say, of 500 ohms.

Then in the first case there will be—

$$\frac{E\ 10}{R^1\ 10 + R\ 500} = 19{\cdot}60 \text{ milliampères.}$$

In the second case $\frac{E\ 10}{R^1\ 100 + R\ 500} = 16{\cdot}66$ milliampères.

From this it will be seen that when the external resistance is very high as compared with the internal resistance—so high that the latter is, compared with the former, almost negligeable—not much is to be gained by selecting cells with a low internal resistance. It may be easily made out, however, that a point can be reached where it becomes of no use to increase the number of high resistance cells in a battery with any expectation of getting a greater yield of current. Take the case of a battery composed of cells, each having an internal resistance equal to 10 ohms and an electro-motive force of 2 volts. One such cell would yield on short circuit 0·2 ampères or 200 milli-ampères. Two cells would yield no more $\frac{E\ 4}{R\ 20} = 200$ milliampères. So also 100 cells arranged in the same way, that is, in series, will yield no more $\frac{E\ 200}{R^1\ 1{,}000} =$ 200 milliampères.

Certainly one hundred such cells could be so arranged as to yield greatly more current than one cell. Let them be arranged so that they form in effect one large cell, one hundred positive and one hundred negative elements joined together. The internal resistance will now be one-hundredth part of what it was before, though the electro-motive force will be but that due to one cell. There is then $E = 2$ volts $R^1 = 0{\cdot}10$ ohms. Applying Ohm's law, it is found that there will now be 20 ampères or 20,000 milli-ampères of current.

When the electro-motive force and also the resistance are known, the amount of current can be calculated, as has been seen, $C = \frac{E.}{R}$

When the amount of current is known, and also the resistance, the electro-motive force can be calculated $E = C\ R.$

When the electro-motive force and also the current are known, the resistance can be calculated $R = \frac{E.}{C}$

To show the application of each phase of the rule, take the case where there is a cell E of 10 volts and $R + R^1$ of 5 ohms $\frac{E\ 10}{R\ 5} = C\ 2$ ampères.

A current of 2 ampères and a resistance of 5 ohms, $C\ 5 \times R\ 2 = E\ 10$ volts.

There is E M F of 10 volts to a current of 2 ampères, $\frac{E\ 10}{C\ 2} = R\ 5$ ohms.

CHAPTER X.

OF RESISTANCE AND ITS MEASUREMENT.

In all calculations relating to current, the factor of resistance is of great importance, as has already been pointed out. If an exhaustive list be made of all the materials, which are commonly called conductors, and of all those commonly called insulators, arranging the series in order of decreasing conductivity ; it would be found, that no hard and fast line of demarcation could be drawn between the conventionally named conductors and insulators. A material is called a conductor when it, relatively to another material, presents a low resistance to the passage of an electrical current. Conversely a material is called an insulator, when it presents a relatively great resistance.

Speaking broadly, the metals are good conductors, some being very much better than others. Silver is the best conductor; copper next, and so on, in order of increasing assistance down the list—silver, copper, gold, zinc, platinum, iron, tin, lead, mercury.

The relative conductivities or resistances of these and many more materials have been estimated. It has been determined that the resistance at O° C of a wire

of annealed silver, one metre long and one millimetre in diameter, is ·01937 ohms. A wire of hard silver of the same dimensions has however a resistance of ·02103 ohms ; one of annealed copper of one metre in length and one millimetre in cross section has a resistance of ·02057 ohms. Hard copper has a resistance, in a wire of the same dimensions as the preceeding of ·02104 ohms. Platinum is to be credited with ·1166 ohms, and iron with ·1251 ohms, for wires of the same length and cross section. A column of mercury of one metre in length and one millimetre in diameter at O° C gives a resistance of 1·2247 ohms; and German silver, for a wire of the length and diameter of one metre and one millimetre respectively, ·2695 ohms. In the fact that a length of wire of given material, and of given length and diameter, gives at the same temperature always the same resistance, lies the possibility of measuring, by comparison, unknown with known resistances.

In different countries, at one time, various units of resistance were employed, as different units of mass and length are still employed. As time goes on, men accustomed to exact measurements tend to make use of a catholic set of units. Thus, the different national units are passing out of use, and are being replaced by the ohm, which is or ought to be based upon the French units of length, mass, and time. It was determined that the standard ohm should be represented by a column of mercury, at O° C, of one square millimetre section, and of a length to be fixed by an international commission. Meantime, however, this new unit is not used ; but one, which was fixed a good many years ago by a committee of the British Association, has been adopted. This one, which differs somewhat from the theoretical unit, is often written as the B.A. unit, to distinguish it from another.

sometimes called the commercial unit. The only one besides the ohm which seems to be much used now is the Siemens unit. This is represented by a column of mercury of one metre in length, and one square millimetre in cross section. The ohm is also represented by a length of mercury column at a fixed temperature. Having fixed the unit of resistance, no matter what it be, it becomes necessary to have convenient units and multiples thereof. These, the instrument makers provide, in coils of wire, generally arranged for convenience in what is called a "resistance box." By means of these coils of wire it becomes possible to measure the resistance of other wires, the resistances of which, we should not otherwise be able to determine. The operation of measuring the resistance of a wire or any other body, which forms or is about to form a portion of an electrical circuit, is in many respects analagous to the operation of determining the weight of a parcel, in an ordinary pair of scales. In the former operation, an unknown resistance is balanced by a known resistance, as in the latter, an unknown weight is balanced by known weights.

The resistance box or balance, generally called Wheatstone's, but in fact due to Christie, has one of its arms provided with coils of various resistances, and these resistances can be placed in circuit in that arm of the balance, while the piece of wire, whose resistance is to be measured, is placed in the other arm. As in a pair of scales, one of the arms is retained for the parcel of unknown weight, and the other for the pound or other weights, which are to be added till equilibrium is obtained. In the ordinary scales, known weights are added to the weight arm, which is lettered B in the figure, until the index leans neither to one side nor to the other.

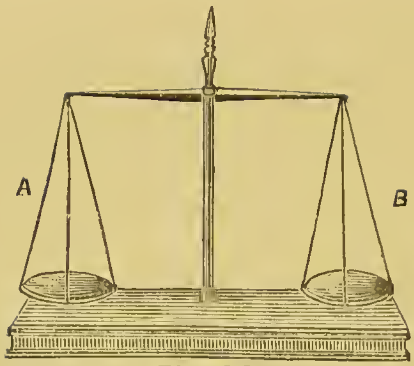

Fig. 22.

When this is the case, it is evident that the weights which have been placed in the one arm are equal to the parcel whose weight had to be determined; the operation then consists in adding together the various weights, which it was required to place in B before the balance was obtained. It is then argued that the weights in the scales are equal, and, knowing how much has been put into B, it is evident what must be the weight in A.

So, using the same letter, and having placed the substance of unknown resistance in the A arm of the Wheatstone bridge, known resistances are added to the B arm until the index of the galvanoscope, which corresponds to the index of the ordinary scales, stands at zero. The resistances, which have been included in the B arm, being known, and equilibrium having been obtained, the resistance of the piece of wire or other substance, which was placed in the A arm is made evident.

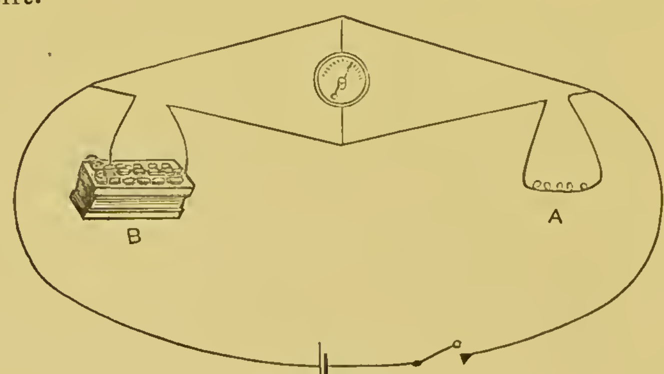

Fig. 23.

As the Wheatstone bridge is made, it is usual to provide for the insertion of resistances up to about 10,000 ohms, arranged in a convenient way so that all combinations can be obtained. It is possible with these numbers, and by proper manipulation to find out a resistance, which may be much greater or much smaller than that of any of the wires to be found in the resistance box. Resistances may, by the use of the proportional arms, be made from $\frac{1}{100}$ to 1,000,000 ohms; although 1 ohm be the lowest individual coil, and 10,000 ohms the greatest possible resistance, when all the coils are in series.

By taking advantage of the great resistance which nearly all fluids with the exception of mercury give, as compared with metals, liquid rheostats, or apparatus by means of which large resistance can be at will included in a circuit, are rendered possible.

It is sometimes necessary, especially in sending currents of electricity through the human body, to commence operations by including in the circuit a large resistance, so as to make the current very feeble. As the current depends upon the electro-motive force, and on the resistance in the circuit, it will be understood that, as resistance is withdrawn, so a greater current will pass. Dilute sulphuric acid has a resistance, length for length, and cross section for cross section, nearly a million times greater than copper; and a solution of sulphate of copper has a resistance nearly ten times as great as that. If then a glass flask, of some length and small cross section, be filled with a sulphate of copper solution, and if, at the bottom of the flask, a metal conductor be fixed, while near the top of the said flask is a second conductor, capable of being pushed down towards the first, it will be possible, when the position of the conductors are as first described, to have a large

resistance in the circuit. This may be gradually taken out by pushing the upper conductor downwards, and thereby shortening the column of high resistance fluid, which is interpolated between the conductors.

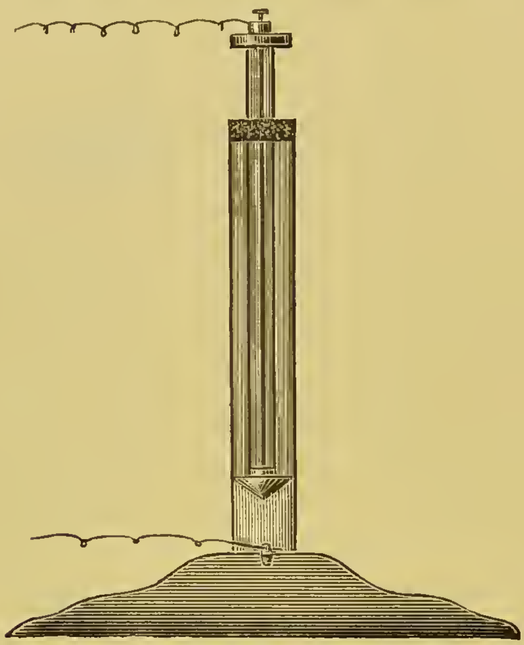

Fig. 24.

If in the circuit here figured a galvanoscope be included, it will be possible to see, by the varying deflection of the needle, how greatly the current increases as the upper conductor is pushed downwards and approaches the lower. The steady progress of the needle is noticeable. It does not move by fits and starts, for the resistance is gradually and steadily withdrawn; therefore the current is gradually and steadily increased.

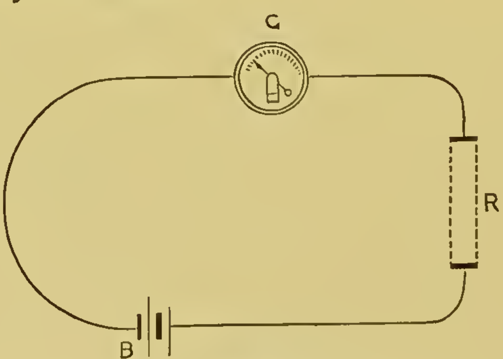

Fig. 25.

The avoidance of jerks and starts in administering a current to a patient is very important, for thereby, what are called induced currents are avoided. These currents and their physiological effects cannot be studied here; but it is necessary to mention, that, when a current is started, or stopped, or increased, or diminished suddenly, another current is induced in a neighbouring conductor, along which no current has been previously flowing, but which is merely contiguous to the conductor, carrying the current. For the manifestation of the induced current, a neighbouring conductor is not required; that one actually carrying the current will serve. The effect is then called self-induction. When a current is suddenly "made," the induced one is in an inverse direction; it is in the same direction as the inducing current when it is suddenly "unmade." When increasing, the direction of the induced is opposite to that in which the inducing current is flowing; when decreasing, the direction of the induced and inducing currents is the same.

CHAPTER XI.

OF CURRENT MEASURES.

The index of the galvanoscope, included in the arrangement, already described, will tell us whether a current flows or does not flow; and doubtless, if the instrument were calibrated, it might be made to tell the amount of current which is flowing. When merely designed to show the presence or absence of a current, it is called a galvanoscope; when it is calibrated so as to show the amount of the current, it is called a galvanometer.

A galvanometer may be any instrument, which measures the amount of work done by a current. The name is generally employed, however, as

descriptive of that form of instrument in which a current of electricity is made to deflect a pivoted magnet from its zero position. The movement of the needle from this position to any other, requires a certain current, and the amount of deflection from zero position of the moveable magnet, is indicative of the current, which compels the change; while the direction, in which the needle moves, is an indication of the direction of the current. The possibility of measuring and detecting the direction is due to the fact, that electrical currents have a directive force upon a magnet.

It is necessary to know, that, if a conductor carrying a current be placed on a horizontally pointed magnet, such as a compass needle, it will cause that needle to move round. The needle will move to right or left, according to the direction of the current in the conductor. Ampère, who first studied the action of currents and magnets on each other, indicated an easy way of remembering the effect of different directional currents upon the magnet. Let AB be a conductor carrying a current, and let the observer imagine himself to be a man swimming along the conductor, in such position as always to swim with the current, and to face the magnet. The north pole of the needle will be always deflected to his left hand.

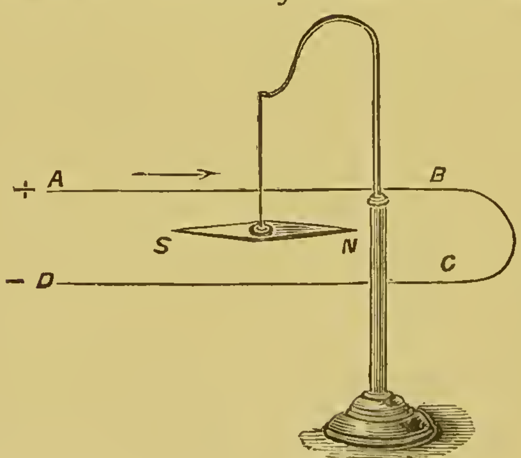

Fig. 26.

This *memoria technica* as here stated seems to indicate, which is the north and which the south pole of a magnet, whose polarities had been unknown, while the direction of the current had been known. When the polarity of the magnet is known, the direction of the current can be, of course, easily deduced by the application of the same rule.

It will be seen from the figure, that the current flowing along the top of the needle from A to B has the same directive action as the current passing from C to D. It might then be concluded, that a current passing along a coil would have a directive force upon a needle, pivotted within the coil. Such is the case, and an important fact is this, that, *cæteris paribus*, the greater the number of convolutions in the coil, the greater will be the deflection of the magnet.

When dealing with a feeble current, it will be necessary, that the number of convolutions in the galvanoscope or galvanometer be many, in order to produce a considerable deflection. If there be a large current, the number will not require to be so great.

It may happen, however, that the same galvanometer will be required to measure currents of greatly differing strengths. The galvanometer, which is calibrated to give readings up to 250 milliampères, may be required to measure up to 500 milliampères. For adapting such a sensitive galvanometer, whose needle would pass beyond the scale if a strong current were to be passed through it, an arrangement is made, whereby one-half or one-third or any desired proportion of the current shall be allowed to pass through the galvanometer. This is done by the addition of a shunt to the instrument.

CHAPTER XII.

OF SHUNTS.

When a current of electricity has two, or it may be more paths provided for its passage, it divides, and passes through these different paths in proportions, inverse to the resistance of the branches. Let the loop ACB be one path, with a resistance of ten ohms, and the loop ADB another, with a resistance of twenty ohms.

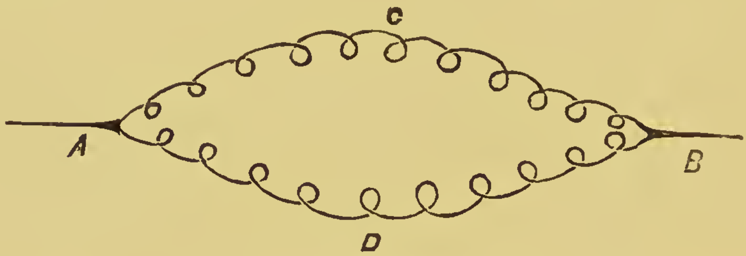

Fig. 27.

Two-thirds of the current will flow along ACB, and one-third by ADB. If the total amount of current passing in a circuit with such loops, where the other resistance in the loops is negligeable, be three ampères, two of them will have passed by the path ACB, and one by that of ADB. Where a number of paths are provided, by the presence of conductors for the flow of current, as shown in the figure, there will be less resistance, than if only one conductor had been provided.

Take a case where there are five paths between A and B, by C, D, E, F, and G, each with a resistance of five ohms, and when the other resistance in the circuit is negligeable, the total resistance will be one ohm, only one-fifth of what it would have been had but one conductor been provided. Thus, if the EMF of the current were one volt, and the internal resistance negligeable, there would be one ampère, or

1000 milliampères of current, when all the five paths C, D, E, F, and G were being made use of. Should, however, the conductors D, E, F, and G be removed, then the current would be reduced to 0·2 ampères, or 200 milliampères. Because, when making the calculation, it would be found, that, instead of dividing the one volt of EMF by one ohm, it would be necessary to divide it by five, as that is the resistance of any one of the conductors C, D, E, F, and G. That the current will divide exactly in proportion to the conductivity of the path lies the possibility of taking from a main conductor of known resistance, whatever proportion of current is desired.

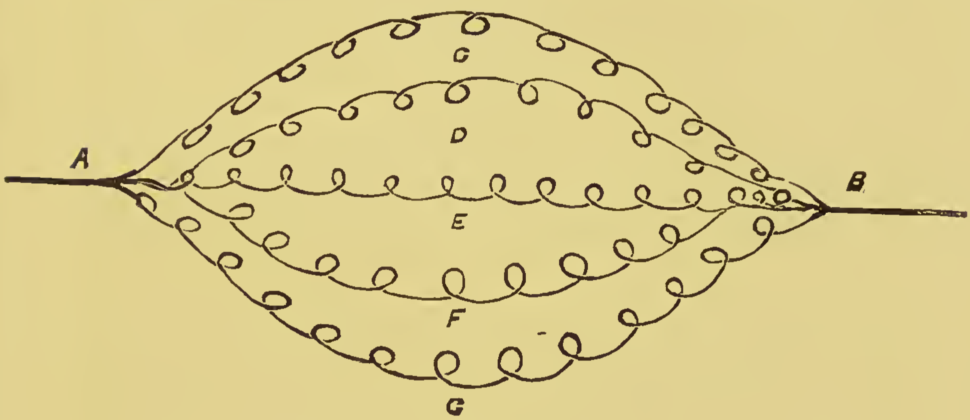

Fig. 28.

A shunt may be put across any portion of a circuit. Let it be assumed, that in a circuit a galvanometer or current measurer is placed, which shows that a current of 250 milliampères is passing. The needle, it may be, has gone nearly to the end of its range, and there is no possibility of measuring a greater current should it be increased. Such a galvanometer can, however, by the addition of shunts, be adapted to measure currents of far greater strengths than 250 milliampères. A shunt, then, is an arrangement, by which, a certain amount of the current can be prevented from passing through the galvanometer. If

the resistance of the coil of the galvanometer be equal to 0·2 ohms, it will be a simple matter to allow half of the current only to pass through the galvanometer, by introducing into the circuit a shunt with a resistance of 0·2 ohms, as is represented in the figure. It will be easily understood that two shunts of 0·2 ohms, or one shunt of 0·1 ohm resistance, will allow only one-third of the current to pass through the galvanometer. Supposing, that in this last case a strength of 50 milliampères were registered, it would mean that 150 milliampères were really passing through the circuit

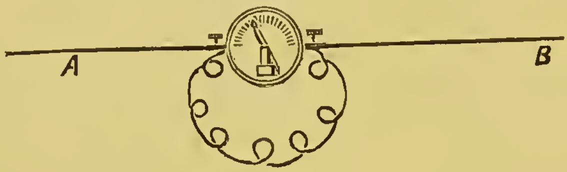

Fig. 29.

Fig. 29 represents a shunt in its most simple form.

CHAPTER XIII.

ELECTROLYSIS.

When the theory of the battery was described, attention was called to the way in which electro-positive hydrogen is attracted to the electro-negative plate in the cell, while electro-negative oxygen is attracted to the positive plate. One would, therefore, expect, that if the terminals from a cell or battery of cells be placed in a conducting liquid, which is an electrolyte—*i.e.*, a fluid susceptible of having its atoms electrically disassociated, and of necessity, therefore, a compound body—an attraction will be exercised by the electro-positive terminal upon the electro-negative atoms, and an attraction by the

electro-negative upon the electro-positive atoms. This process will, indeed, take place; it is known as electrolysis, and it plays an important part in many arts.

In a very simple case, that of the electrolysis of water, which may be studied with an instrument known as a voltameter, it is found that, when in a pneumatic trough arrangement, test tubes are placed over the two terminals from a cell or battery of cells, hydrogen, in its combining proportion with oxygen in water, comes off at the plate, which is connected with the negative pole of the cell or battery, and oxygen comes off at the plate which is connected with the positive pole of the cell or battery of cells.

By means of a large battery Sir Humphrey Davey electrolysed potash, and found that it consisted of potassium and oxygen. Salts can be readily split up into their constituents by the same means.

Faraday has laid down the principal laws of electrolysis. He found that the same electrical current splits up the traversed bodies into their chemically equivalent quantities, the weights of the separated elements being as their chemical equivalents.

Electrolysis may not do more than split up compounds into their electro-positive and electro-negative constituents; the electrical work, so far at least as the cell or battery electricity is concerned, may stop there; but the results, in a liquid containing several electrolytes, may be of a most varied and interesting kind. The process by which nascent hydrogen is set free at one pole and nascent oxygen at the other, in a fluid consisting of any reducible or oxydisable body, must result in chemical action of an interesting and often of a most complicated nature.

CHAPTER XIV.

MODE OF APPLICATION.

The application of the galvanic current to the treatment of disease can now be considered, and the reason why certain instruments are better than others will be understood. For this purpose, the method employed by Dr. Apostoli, of Paris, in the treatment of fibroid tumours of the uterus will be described; for, with the exception of the special electrodes used in the treatment of differing diseases, the apparatus required will be found to be suitable for general application, and with a little ingenuity and thought, the mode of making the applications can be adapted to the treatment of other diseased conditions, and to the reduction of new formations. It will be found also that the precautions, which have to be taken when the treatment is applied to uterine tumours will have to be borne in mind, when such diseases, as enlargements of the thyroid or of the prostrate are treated.

The apparatus, to be described, has been found by practical experience to be the best, or at least as good as any, and it consists of a battery, a galvanometer, calibrated to serve as a milliampère meter, a rheostat, a commutator or current changer, and the outside or inert electrode. Before the consideration of each part of this apparatus is taken up, there must be a clear understanding of what work has to be done, and how the apparatus is to do it. Neither the physical nor physiological action can be entered into, though it may be stated that the factors at work seem to be of various kinds. It is desired to pass a current of electricity through a part of the human body, and it will not have to be forgotten, that this current may be required to be of a strength of three hundred

milliampères in exceptional cases. More than this is required, for it will never do, to suddenly turn on a current of such a strength; not only, on account of the great shock or jerk which would result; but, because many a patient cannot suffer, especially at first, a current of one hundred milliampères, even if that strength be gained gradually. It has been said that the sudden passage or stoppage of a current of two or three hundred milliampères through a uterine tumour might cause death, but this seems to be a mistake. The current then must be capable of being gradually increased, and gradually decreased. In addition to this, it must be passed through the skin without causing much pain. If the work of one day is to be compared with that of another, or if the quantity of electricity, passed through one person, is to be compared with the amount passed through another patient, an instrument for measuring the current, must be included in the circuit. And, for convenience, an arrangement by means of which the direction of the current can be changed, without having to fix and unfix wires or screws, ought to be taken advantage of.

To sum up the requirements in a few words, there must be an apparatus for generating the current—the battery; for gradually increasing and gradually decreasing it—the rheostat; for passing it through the skin without causing much pain—the external clay electrode; for bringing it to the seat of disease—the internal electrode; for measuring the amount—the galvanometer; and finally, for changing, with as little trouble as possible, the direction of the current—the commutator.

THE BATTERY.—For the consulting room, a battery composed of from thirty to forty Leclanché cells, the capacity of whose outer vessel when filled with fluid will be about one quart, is extremely convenient. The

electro-motive force of each of these cells will be 1·48 volts, and the resistance perhaps half an ohm. It is important that information on the latter point be obtained. As the cells are to be joined together in series, a current of nearly three ampères would flow if the two poles of the battery of thirty cells were joined together by a stout copper wire, whose resistance were supposed to be negligeable—

$$C = \frac{\text{EMF } 44{\cdot}4}{\text{R}^1\ 15} = C = 2{\cdot}9 \text{ ampères.}$$

The resistance of the body, and of the wires, screws, etc., outside of the battery, has to be taken into account; and, when everything is in good working order, this resistance, which includes the resistance of the battery and the resistance of the tissue included in the circuit, will be from about 150 to 200 ohms. The result will be, that a current of from 206 to 269 milliampères will flow through the circuit.

$$C = \frac{\text{E } 44{\cdot}4}{\text{R}^1\ 15 + \text{R } 150} = C = 269 \text{ milliampères.}$$

$$C = \frac{\text{E } 44{\cdot}4}{\text{R}^1\ 15 + \text{R } 200} = C = 206 \text{ milliampères.}$$

Little or no advantage would be gained by reducing the internal resistance at the expense of the electro-motive force, as the external resistance is so great in comparison to that in the battery itself. For example, suppose the internal resistance be reduced by one-half, as may be done by arranging the cells partly in parallel and partly in series, making fifteen groups of two cells each, there would then be in effect, fifteen large cells, each with an electro-motive force of 1·48 volts and each with a resistance of ·25 ohms. The electro-motive force of the battery would be 22·2 volts, and the resistance 3·75 ohms. To this internal

resistance, is added the external resistance of 150 ohms, and the result is—

$$C = \frac{EMF\ 22{\cdot}2}{R^1\ 3{\cdot}75\ R\ 150} = C = 144 \text{ instead of } 269 \text{ milliampères.}$$

But, suppose, that in a battery of thirty small Leclanché cells joined in series the resistance of each cell be 10 ohms, the electro-motive force being as before, the result will be—

$$C = \frac{EMF\ 44{\cdot}4}{R^1\ 300\ R\ 150} = C = 98 \text{ milliampères}$$

The second case shows how, for the work which is required, internal resistance has been reduced at the cost of diminishing the usefulness of the battery, while in the last it has been shown how want of attention to lessening the internal resistance may also result in a similar diminution in usefulness.

The battery should be kept in a cool, equable temperature. A cellar is often convenient for this purpose. Even when it is given plenty of work to do, a battery of Leclanché cells will not require to be looked at oftener than once every six months or so. Perhaps twice a year, it will be necessary to replace the old sal ammoniac solution by new, and to clean up the elements of zinc, though it is not necessary to have them re-amalgamated, as is often done. As time goes on, it will be found that the binoxide of manganese loses its power of destroying the hydrogen bubbles of gas, thus necessitating the refilling of the porous pot. In this connection a small instrument usually called a detector will be found of service. It consists, in its simplest form, of two wires attached to a galvanometer, and is used in the following way. The free ends of the wires are applied, one to the zinc, and the other to the carbon of each cell. Should the

internal resistance in any one have become so great that the cell is practically useless, a deflection of the galvanometric needle sensibly less than that observed when a good cell is tested will be observed. Such a cell had better be removed from the battery, as it may be doing more harm than good by increasing the resistance in the circuit, far out of all proportion to the advantage gained by its electro-motive force. The cell may be actually removed, or if this be not convenient, it may be cut out by being short circuited, *i.e.*, a stout copper wire may be made to connect the carbon and zinc of the defective cell, all the other connections being left as before, thus allowing the current to escape the necessity of going through that cell, by taking the passage of least resistance.

One objection has been urged against the employment of the Leclanché battery, which would be of importance, were it desired to use the battery for an hour or two at a time. This is, that in time, the cells become polarised. It is true, that the binoxide of manganese is unable to destroy the hydrogen as quickly as it passes to the carbon ; if, however, the battery be but slightly exhausted in this way, a very few minutes' rest will suffice for the manganese to overtake its work. Should the current be required for twenty minutes or half-an-hour at a time, it will fall off not more than five or ten milliampères, with large resistance in circuit. As a rule, applications are not made for more than five minutes, and even in dispensary or hospital practice it has been found that it is scarcely possible to make more than eight applications within the hour, so that the battery will have twenty minutes' rest to every forty minutes' work. This is scarcely enough, and after two or three hours of such hard usage, a rest of ten or fifteen minutes must be given in addition. In private practice, where it is

impossible to get on so quickly, a battery of good Leclanché cells never become polarised.

THE RHEOSTAT.—The figure on page 42 represents a simple and reliable rheostat. With a column of a weak solution of sulphate of copper of eight or ten inches in height and three-quarters of an inch in cross section, no shocks need be given, and the amount of current can be regulated to a nicety. The solution of copper can be scarcely too weak, as a bad conductor is what is required, indeed when the plate attached to the upper wire touches the fluid the solution should be a bad enough conductor to prevent the circulation of any considerable amount of current.

Instead of a rheostat it is customary to use an arrangement known as a collector. Here the wires from each cell or group of cells are fastened to a small plate or screw; and by means of a handle, the current can be increased or diminished by one cell or one group of cells at a time. It will be seen that, as the current must, therefore, be suddenly increased and also as suddenly decreased, there must be an induction shock produced whenever a single cell is added to or taken out of the circuit. Some patients do not feel any disturbance from this, but to others it is undoubtedly disagreeable, and possibly a source of danger; and the large number of wires which are required is also a great disadvantage. The advantage, if advantage it be, of a collector appears to lie in this, that there is some slight economy, as when twenty cells of a thirty celled battery are being used the remaining ten are not employed; whilst with a rheostat the whole number of cells must be in use, no matter how small a current may be required. Sometimes a collector and a rheostat are used, but no advantage can be gained by doing so.

It should have been mentioned that the wires leading from a battery are called rheophores, and the free ends of these wires are called, when considered in their relation to electrolysis, electrodes.

To complete a circuit, in which is included a part of the human body, it is necessary to have both electrodes applied to that body. That one, attached to the rheophore from the positive pole, is, of course, the one by which the electricity is considered to enter, while it is supposed to pass back to the battery by the other, or negative one. When treating disease, these two electrodes have been, for convenience, sometimes called the active and the inactive electrode. This is intended to signify that the one which is nearest to the seat of disease is the active, and the other the inactive. Those terms are not by any means correct. It is beyond the scope of this work to deal with the so-called active electrodes, except to point out that the smaller this electrode is, the greater, as a rule, will be the result of the application. This is due to the condensation, so to speak, of the current, at or near, the diseased spot with which it is in contact. The inactive electrode, on the other hand, requires a little attention.

When speaking of shunts in chapter XII., it was pointed out, that five times more current will pass through five paths, each having the same resistance, than will flow, should four of those paths be removed; because, there will be five times greater resistance in the latter case; or, what is the same thing, four fewer paths for its passage, will have been provided. The inactive electrode is placed on the skin, the skin is not a good conductor, and it will be evident that an electrode five times larger than another will allow five times the quantity of electricity to pass, if that be the only resistance in the circuit. It

will, therefore, be necessary to have this electrode large. It must also, for evident reasons, be a good conductor, so as at the same time to offer little resistance, and also to allow the electrical current to flow all through it, and thus prevent the current being stronger at one part than at another. At present, the most convenient material for this electrode is ordinary sculptors or modeller's clay. It has unfortunately two drawbacks, it is cold and it is not elegant, though it is not so disagreeable to work with as is sometimes stated. The size of this pad of clay will vary—it may be small, when a weak current is being used; when it is wanted to get strong current into the body it will have to be made larger. The resistance is thus diminished, and less pain is caused by spreading the current over a larger surface of skin, and thus reducing its strength at any one part; as there is no advantage in concentrating the current away from the disease, and the object is to get through the skin as easily as possible.

The Galvanometer.—The current measure does not require any further description. That of Gaiffe, calibrated so as to read to 200 or 250 milliampères without shunting the current, and provided with at least a single shunt of its own resistance, will be found to be reliable and not expensive. With such a shunt, currents of 400 and 500 milliampères may be indicated.

The Commutator.—The current changer is simply what its name implies; in the "barrel" commutator, by giving a handle a quarter turn the positive wire becomes the negative, and *vice versâ*. In the "pedal" commutator the depression of one or the other key gives the same result.

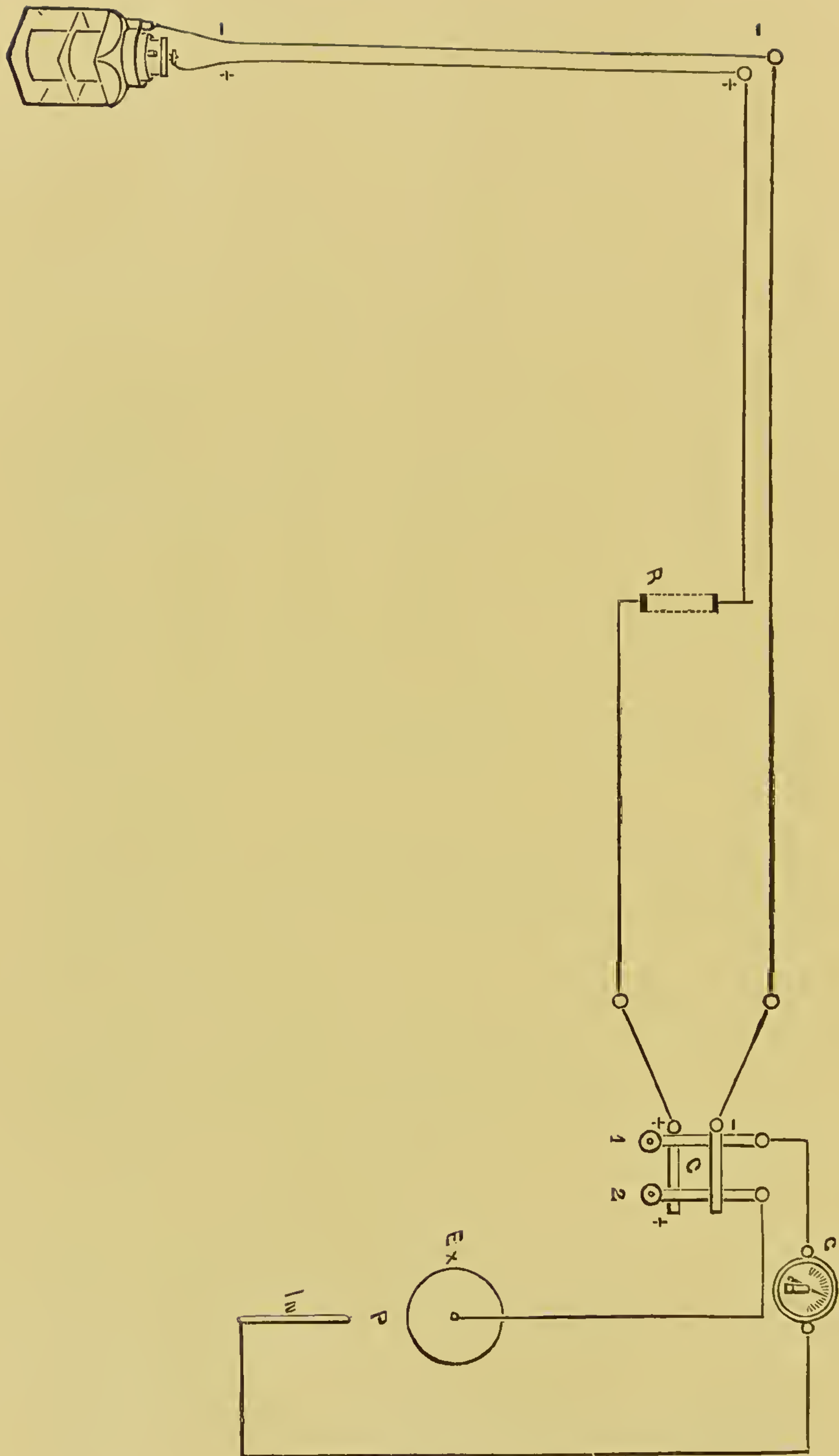

Fig. 30.

The diagram shows what the arrangement of a battery and its accessories might be. The battery is represented as being at some distance—it may be in the cellar. Wires from it are run to two binding screws in the consulting room, and one screw is marked + and the other — according as the wire from the positive or negative terminal of the battery is attached to it. For the sake of definiteness the positive wire is shown to be the one in whose course is inserted the rheostat and from thence it passes to one of the binding screws of the commutator. The negative wire runs direct to the other fixed cross bar marked — in the diagram.

The flexible wire to the "internal" electrode is attached to the left hand flexible and movable brass strip of the commutator marked "In." The flexible wire running to the external electrode is marked "Ex." If now, the connections being as shown in the diagram, flexible strip of brass No 1 be depressed so that it loses connection with fixed cross bar — and makes connection with fixed cross bar +, a positive current will flow by way of the internal electrode. If No. 1 flexible strip be held in this connection, the current will continue thus to flow. If it be released no current will flow. If No. 2 flexible brass bar be depressed, a positive current will flow by way of the external electrode. Thus, as No. 1 or No. 2 is depressed so does the current pass by way of the internal or by way of the external electrode.

If by accident both be depressed at the same time no current will flow so that the only possible error of consequence lies in depressing 1 when 2 should have been depressed, or *vice versâ*.

The internal resistance was taken at 150 or 200 ohms, it must not for a moment be supposed that this is the resistance of the body under any circumstances, but only when Dr. Apostoli's apparatus for treating uterine fibroids is used. The important factor in the reduction of the resistance is the large external electrode of clay. If, instead of presenting a surface of eighty square inches it were only the size of one square inch, the resistance would be not only increased, but great pain accompanied by charring of the skin would be the result; and to obtain the same amount of current a much more powerful battery would be required.

The most convenient portable battery is one of bisulphate of mercury, manufactured by Gaiffe, of Paris. This is a form of the Marie Davy battery previously described.

THE EXPRESS PRINTING CO., LIMITED, BURY STREET, E.C.—TELEPHONE 1254.

0/7